XVII. *On the Chemical Intensity of Total Daylight at Kew and Pará*, 1865, 1866, and 1867. *By* HENRY E. ROSCOE, *F.R.S.*

Received May 14,—Read June 20, 1867.

PART I.—THE KEW OBSERVATIONS.

IN the year 1864 I communicated to the Royal Society* the description of a method for the Meteorological Registration of the Chemical Intensity of Total Daylight, founded upon an exact measurement of the tint which standard sensitive paper assumes when exposed for a given time to the action of daylight.

During the last two years measurements of the chemical intensity, according to this plan, have, through the kindness of Dr. BALFOUR STEWART, been made regularly every day at the Kew Observatory by Mr. T. W. BAKER, and thus the practicability of carrying out a continued series of observations according to this method has been effectually and satisfactorily tested.

Owing to the press of regular work at the observatory only three separate registrations of chemical intensity could be made at different hours each day. Hence the results obtained do not in any way indicate the hourly variation of chemical intensity, nor can even the individual integrals of daily intensity, giving the mean chemical action each day, be said to do more than exhibit approximately the changes which go on from day to day. The monthly integrals, on the other hand, each calculated from a large number of observations, show with a great degree of accuracy the rise and fall of the chemical intensity with the changing seasons of the year, and enable us to deduce from this the first series of observations of the kind, the mean monthly and yearly chemical intensities at Kew for 1865, 1866, and 1867.

The hours at which the chemical intensity was registered each day were those chosen for the reading of the meteorological instruments, viz. 9^h 30^m A.M., 2^h 30^m P.M., and 4^h 30^m P.M. The condition of the sun's surface as regards freedom from cloud, the amount of the cloud, the temperature (wet and dry bulb) and the atmospheric pressure were also noted.

As an example of the results thus obtained, the observations made in the month of July 1866 have been chosen as exhibiting well the great changes in chemical intensity produced by varying cloud and sunshine.

* Bakerian Lecture, Philosophical Transactions, 1865, Part II. p. 605.

Table I.

Observations of Chemical Intensity at Kew, July 1866.

Date.	Time.	Chemical intensity.	Sun's surface.	Clouds.	Thermometers Fahr. Dry.	Thermometers Fahr. Wet.	Barometer at 32° F.
1866.	h m						
July 2.	9 30	Rain.					inches.
	2 30	0·270	Light clouds.	8	63·7	54·9	29·267
3.	9 45	0·335	Clouded over.	9	57·1	51·1	·384
	2 40	0·335	Id.	9	59·8	54·6	·374
	4 50	0·227	Light clouds.	4	58·6	54·5	·338
4.	9 50	0·430	Clouded over.	10	56·8	53·8	·451
	2 45	0·190	Id.	9	63·5	55·7	·477
	4 30	0·126	Id.	9	60·7	55·7	·499
5.	9 40	0·320	Id.	6	60·8	53·2	·481
	3 0	0·355	Unclouded.	5	60·1	56·4	·513
	5 0	0·180	Clouded over.	5	59·7	52·9	·524
6.	9 30	Rain.					
	4 30	0·187	Light clouds.	4	60·3	53·7	·665
7.	9 45	0·122	Clouded over.	8	57·0	50·1	·961
	2 0	0·143	Unclouded.	5	63·8	53·7	30·013
9.	9 40	0·142	Clouded over.	10	63·6	59·9	·179
	2 30	0·315	Very light clouds.	5	72·8	65·2	·179
	4 30	0·160	Id.	6	73·8	66·0	·188
10.	9 30	0·390	Unclouded.	0	71·3	64·7	·295
11.	2 40	0·165	Hazy.	0	74·8	66·0	·265
	4 30	0·062	Clouded over.	9	75·5	66·0	·249
12.	9 40	0·560	Light haze.	0	75·7	67·5	·204
	2 40	0·630	Unclouded.	4	81·1	69·2	·151
	5 0	0·237	Id.	1	82·2	69·5	·129
13.	9 40	0·640	Id.	0	78·3	70·5	·057
	4 50	0·280	Id.	5	79·8	66·5	·055
14.	9 30	0·380	Haze.	4	69·2	63·3	·141
	2 0	0·550	Unclouded.	4	80·6	69·6	·125
16.	2 50	0·177	Clouded over.	5	71·8	62·0	·044
17.	9 40	0·107	Id.	10	65·9	58·5	·050
	2 40	0·185	Id.	9	68·1	59·6	·012
	4 30	0·156	Id.	10	65·9	58·5	29·997
18.	9 50	0·305	Light clouds.	4	62·4	55·3	·996
	2 40	0·197	Unclouded.	3	68·1	56·8	·952
	4 30	0·177	Id.	3	68·6	57·4	·936
19.	3 0	0·185	Clouded over.	8	65·6	59·0	·886
20.	9 40	0·257	Id.	9	57·8	50·6	30·058
	2 30	0·355	Unclouded.	4	65·7	56·8	·054
	4 30	0·203	Id.	1	68·7	58·3	·036
21.	9 40	0·177	Unclouded: very thin haze.	0	64·2	58·2	·095
	2 0	0·345	Unclouded.	1	75·5	61·2	·051
23.	9 30	0·217	Clouded over.	10	56·0	52·3	·042
	2 40	0·280	Unclouded.	1	65·4	56·7	29·985
	4 30	0·237	Id.	1	65·7	56·9	·986
24.	9 30	0·247	Clouded over.	10	57·8	54·1	30·037
	4 30	0·089	Id.	9	61·7	53·9	·056
25.	9 40	0·140	Id.	9	58·4	53·0	·204
	2 40	0·187	Id.	10	62·6	55·9	·212
	4 30	0·064	Id.	10	61·5	55·7	·217
26.	2 30	0·177	Id.	10	66·6	58·5	·083
	4 30	0·063	Id.	10	64·6	57·5	·063
27.	9 50	0·063	Id.	10	61·4	59·7	29·823
	2 45	0·092	Id.	10	63·2	59·8	·754
	4 40	0·088	Id.	10	64·8	60·8	·719
28.	9 30	0·193	Id.	8	65·2	59·7	·654
	1 40	0·112	Id.; light rain.	10	64·8	61·1	·645
30.	......	Rain.					
31.	......	Rain.					

The integrals of daily mean chemical intensity obtained from the numbers in column 3 of the preceding Table by the method described in the above-mentioned memoir, are as follows:—

Daily Mean Chemical Intensity.

(Intensity 1·0 acting for 24 hours =1000.)

July 3rd, 1866	138·1	July 18th, 1866	119·4
,, 4th ,, ...	125·1	,, 20th ,, ...	119·5
,, 5th ,, ...	140·7	,, 23rd ,, ...	106·6
,, 9th ,, ...	91·6	,, 25th ,, ...	67·7
,, 12th ,, ...	229·0	,, 27th ,, ...	35·8
,, 17th ,, ...	60·6		

Monthly mean . . . . 112·2

On the days omitted the number of observations made was too small to enable a determination of daily mean intensity to be made.

In a similar manner the daily mean chemical intensity for every day on which a sufficient number of observations were made, has been determined from April 1, 1865, to April 1, 1867. Table II. contains the numbers thus obtained.

TABLE II.—Daily Mean Chemical Intensities at Kew, 1865–66–67.

(Intensity 1·0 acting for 24 hours = 1000.)

Date.	Intensity.	Date.	Intensity.	Date.	Intensity.	Date.	Intensity.	Date.	Intensity.
1865.		1865.		1865.		1865.		1865.	
April 1.	69·2	May 12.	105·7	June 23.	128·1	Aug. 24.	101·3	Oct. 10.	38·9
3.	41·0	15.	40·1	26.	16·7	25.	62·3	11.	29·5
4.	35·9	16.	99·4	27.	79·5	28.	44·3	12.	37·9
5.	28·6	17.	60·6	28.	87·2	29.	85·7	13.	19·4
6.	66·0	18.	129·8	29.	15·2	30.	80·3	16.	18·5
7.	42·9	19.	109·1	July 3.	179·5	31.	70·1	17.	25·9
8.	96·7	22.	220·8	4.	120·5	Sept. 1.	88·1	20.	24·0
10.	158·2	24.	122·1	5.	73·1	6.	195·5	25.	26·8
11.	78·1	26.	160·0	6.	103·9	7.	244·7	Nov. 3.	14·8
12.	50·5	29.	115·5	7.	132·0	8.	189·5	4.	16·6
13.	86·8	30.	100·0	10.	110·3	11.	64·2	6.	12·0
15.	36·3	31.	64·6	11.	133·3	12.	113·4	7.	9·2
18.	110·9	June 1.	53·1	14.	124·7	14.	129·8	8.	12·0
20.	73·6	2.	38·0	19.	103·9	15.	165·7	9.	15·7
21.	125·3	6.	76·0	20.	110·4	18.	113·4	10.	16·7
24.	82·4	7.	177·0	21.	64·9	19.	75·4	11.	17·6
25.	87·9	8.	64·6	24.	26·0	20.	102·2	13.	12·9
26.	89·0	9.	144·5	28.	90·9	22.	97·9	15.	13·9
27.	106·6	12.	108·7	Aug. 1.	46·7	25.	50·7	23.	12·9
May 1.	54·9	13.	135·5	4.	74·0	28.	64·2	24.	12·9
2.	91·6	14.	96·2	8.	100·0	29.	24·9	27.	13·9
3.	84·0	15.	68·0	14.	88·1	Oct. 2.	44·0	30.	6·5
4.	59·1	19.	89·7	17.	100·0	3.	34·3	Dec. 1.	2·8
5.	61·1	20.	61·5	18.	74·0	4.	12·9	2.	8·3
8.	68·8	21.	98·7	21.	137·6	5.	44·5	4.	9·2
9.	115·9	22.	53·8	22.	114·3	6.	39·8	8.	5·6

TABLE II. (continued.)

Date.	Intensity.	Date.	Intensity.	Date.	Intensity.	Date.	Intensity.	Date.	Intensity.
1865.		1866.		1866.		1866.		1866.	
Dec. 11.	4·6	Feb. 21.	21·3	April 26.	39·1	July 7.	91·6	Dec. 14.	19·5
12.	8·3	23.	25·4	27.	105·1	12·	229·0	18.	8·8
13.	6·5	24.	36·1	30.	27·3	17·	60·6	19.	18·5
14.	12·0	28.	28·9	May 2.	48·0	18.	119·4	20.	9·6
16.	6·4	March 2.	43·8	3.	47·3	20.	119·5	27.	18·2
18.	2·8	3.	34·4	4.	80·9	23·	106·6	31.	14·6
20.	9·2	5.	31·0	8.	94·5	25·	67·7	1867.	
21.	12·0	7.	31·0	9.	56·9	27.	35·8	Jan. 16.	13·9
22.	5·6	8.	23·1	14.	60·7	Aug. 5.	71·6	17.	12·4
28.	9·3	9.	24·1	15.	61·9	13.	81·0	22.	7·6
1866.		10.	19·8	17.	76·1	21.	92·0	23.	4·8
Jan. 1.	19·7	13.	30·5	18.	75·6	23.	69·0	24.	5·7
2.	15·2	14.	41·3	22.	63·8	27.	118·1	25.	1·6
3.	14·2	15.	37·2	23.	98·0	31.	143·7	29.	12·4
5.	9·3	16.	37·4	28.	89·8	Sept. 3.	215·0	Feb 1.	8·6
6.	11·3	19.	9·3	29.	86·9	10.	88·5	2.	12·8
9.	22·1	20.	13·2	30.	60·7	13.	69·5	5.	19·0
10.	7·9	23.	55·9	31.	49·8	20.	45·1	6.	12·4
12.	17·2	26.	42·4	June 1.	66·1	27.	90·3	7.	21·9
15.	22·1	27.	18·2	2.	134·5	28.	93·8	8.	8·6
20.	20·1	28.	26·5	4.	93·8	Oct. 1.	65·9	11.	13·3
23.	22·6	29.	32·0	5·	52·1	2.	35·4	12.	10·5
24.	19·2	April 3.	24·9	7.	114·1	3.	80·1	13.	16·7
25.	13·2	5.	24·9	9.	86·5	5.	35·8	14.	18·6
26.	9·8	6.	28·6	13.	33·1	16.	23·9	15.	26·7
27.	8·8	7.	7·7	14.	94·6	17.	27·0	19.	18·6
29.	23·6	9.	5·9	15.	48·0	23.	19·5	20.	28·0
30.	16·2	10.	38·5	16.	79·3	24.	34·5	25.	28·6
Feb. 1.	16·7	11.	25·4	19.	46·7	Nov. 14.	20·8	March 4.	13·3
5.	20·4	12.	60·7	20.	106·4	20.	13·7	5.	20·0
6.	25·0	13.	52·2	21.	90·6	21.	19·5	6.	20·0
8.	37·5	14.	38·5	22.	111·6	23.	16·6	8.	6·2
9.	20·0	17.	67·4	25.	47·5	24.	16·6	15.	29·5
10.	24·0	18.	39·8	26.	100·2	28.	19·5	20.	36·2
12.	19·7	19.	75·2	27.	99·5	29.	19·5	21.	23·8
13.	26·4	20.	38·9	28.	127·6	30.	15·6	26.	42·8
15.	20·0	21.	109·7	29.	104·0	Dec. 1.	9·0	28.	50·9
17.	13·7	22.	80·4	July 3.	138·1	8.	20·1		
19.	29·5	24.	83·6	4.	125·1	10.	14·1		
20.	24·0	25.	73·7	5.	140·7	13.	7·8		

The first result which presents itself from the daily observations is that the mean chemical intensity for hours equidistant from noon is found to be constant; that is, for equal altitudes of the sun the chemical intensities are equal. Thus the mean of all the morning observations in 1865 (207 in number) was at $9^h\ 34^m$ A.M. $=0{\cdot}153$; that of the afternoon observations in the same year (197 in number) was at $2^h\ 27^m$ P.M. $=0{\cdot}159$; whilst in 1866 the mean of the morning observations (283 in number) was at $9^h\ 49^m$ A.M. $=0{\cdot}119$, and the afternoon observations (274 in number) at $2^h\ 29^m$ P.M. $=0{\cdot}116$. The morning observations in 1867 (62 in number) at $9^h\ 50^m$ gave 0·044, the afternoon (58 in number) at $2^h\ 26^m$ gave 0·047. These give

	Chemical intensity.
Mean of 552 morning observations in 1865–67 at $9^h\ 41^m$ A.M.	$=0{\cdot}105$
Mean of 529 afternoon observations in 1865–67 at $2^h\ 27^m$ P.M.	$=0{\cdot}107$

Hence we may with certainty conclude that when the disturbing causes of cloud &c. are eliminated, the daily maximum of chemical intensity corresponds to the maximum of the sun's altitude, and that the chemical intensity exhibits no sign of a post-meridian maximum, as is observed in the measurements of hourly temperature.

In order to obtain an expression for the relation existing between the sun's altitude and the chemical intensity of total daylight, a much larger number of observations than the foregoing must be made at widely differing altitudes, either on the same day or on consecutive days. Such a series of observations was made at Heidelberg (see Proceedings Roy. Soc. No. 81, 1866) on a cloudless day. The relation between the sun's altitude and the chemical intensity as found in these determinations is graphically represented in fig. 1A, Plate XXI., and is seen to be a straight line, the abscissæ representing the altitude and the ordinates the corresponding chemical intensity. The formula

$$CI_a = CI_0 + \text{const} \times a$$

represents this relation, where CI_a signifies the chemical intensity at any altitude (a) in circular measure, CI_0 the chemical intensity at the altitude 0, and const. is a number to be calculated from the observations. That this formula closely represents the relation in the case of the Heidelberg observations is seen from the agreement of the observed with the calculated intensities.

Altitude.	Chemical Intensity. Observed.	Chemical Intensity. Calculated from formula.
7° 15′	0·050	0·050
24 43	0·200	0·196
34 34	0·306	0·276
53 37	0·437	0·435
62 30	0·518	0·506

A similar series of observations made at Pará (see page 565 of this paper) under a tropical sun in April last, in the middle of the rainy season, shows that a similar relation holds good between the chemical intensity and the sun's altitude even when the sky is not cloudless.

No. of expts.	Sun's mean altitude.	Chemical Intensity. Observed.	Chemical Intensity. Calculated from formula.
22	73° 40′	0·964	0·959
11	60 40	0·769	0·800
11	49 28	0·685	0·666
10	22 58	0·344	0·338

This relation is graphically represented in fig. 1 B, Plate XXI.

Assuming, as we may fairly do, that the same relation between the sun's altitude and chemical intensity holds good at Kew as at Heidelberg and Pará, the value of the inten-

sity at noon can be calculated from the observations at $2^h\ 30^m$ and $4^h\ 30^m$ P.M. The observed values of the monthly mean chemical intensities at $9^h\ 30^m$ A.M., $2^h\ 30^m$ P.M., and $4^h\ 30^m$ P.M., from April 1865 to April 1867, are given in Table III.; the values of the intensities at noon have been calculated by help of the foregoing formula.

TABLE III.

Month.	Hour.	Mean intensity.	Month.	Hour.	Mean intensity.	Month.	Hour.	Mean intensity.
1865.	h m		1865.	h m		1866.	h m	
April.	9 30	0·195	Dec.	9 33	0·029	August.	9 34	0·194
	12 0	0·297		12 0			12 0	0·280
	2 25	0·215		2 26	0·020		2 30	0·210
	4 38	0·112	1866.				4 42	0·115
May.	9 30	0·211	January.	9 34	0·038	Sept.	9 45	0·172
	12 0	0·356		12 0			12 0	0·286
	2 21	0·240		2 26	0·047		2 32	0·187
	4 30	0·115	Feb.	9 39	0·051		4 38	0·058
June.	9 33	0·192		12 0	0·094	October.	9 41	0·085
	12 0	0·313		2 26	0·065		12 30	0·088
	2 26	0·223		4 31	0·021		2 30	0·059
	4 39	0·116	March.	9 35	0·081		4 34	0·019
July.	9 35	0·218		12 0	0·101	Nov.	9 37	0·042
	12 0	0·283		2 30	0·075		12 0	0·057
	2 30	0·214		4 31	0·041		2 27	0·035
	4 30	0·129	April.	9 37	0·129		4 21	0·002
August.	9 39	0·177		12 0	0·163	Dec.	9 43	0·028
	12 0	0·254		2 31	0·116		12 0	
	2 28	0·187		4 43	0·057		2 32	0·016
	4 44	0·104	May.	9 37	0·167	1867.		
Sept.	9 39	0·236		12 0	0·259	January.	9 50	0·033
	12 0	0·397		2 28	0·164		12 0	
	2 38	0·271		4 48	0·067		2 31	0·019
	4 35	0·106	June.	9 43	0·205	Feb.	9 46	0·042
October	9 31	0·066		12 0	0·248		12 0	0·080
	12 0	0·063		2 33	0·183		2 27	0·053
	2 32	0·042		4 43	0·106		4 30	0·012
	4 29	0·013	July.	9 38	0·229	March.	9 53	0·057
Nov.	9 37	0·046		12 0	0·330		12 0	0·099
	12 0			2 32	0·238		2 21	0·071
	2 29	0·025		4 39	0·141		4 36	0·033

The relations existing between the sun's altitude and the mean monthly chemical intensities are graphically represented (for 1865) in fig. 2, Plate XXI.; and (for 1866) in fig. 3, Plate XXI. The ordinates denote the intensity, and the abscissæ the corresponding altitude of the sun.

From the variation in direction of the straight lines representing the relation of intensity to altitude for the different months, it is clear that in each month a different value exists for the constant of the formula, which in fact represents the degree of atmospheric opalescence, the amount of cloud, and the various other factors which, in addition to the sun's altitude, influence the chemical intensity.

That the simple relation which has been shown to hold good when the sun has reached a certain altitude does not apply in the case of low altitudes, is distinctly seen from the above-mentioned figures. When the sun is only a few degrees above the

horizon, the disturbing phenomena of opalescence come into play, and the values of the further and yet undetermined terms of the expression become so large as materially to affect the result. It is only in the case of the Heidelberg observations that the first terms of the series express the relation as low as 8° of altitude, and this is to be explained by the fact that the observations at Heidelberg were made at an elevation of 1900 feet above the sea-level, and therefore at a situation above a great portion of the denser layers of the atmosphere in which the phenomena of opalescence are most marked.

The curves on fig. 4, Plate XXII., show the rise and fall of monthly chemical intensity with the hour of the day for the months of January, February, and March 1867, and April, May, and June 1865; those on fig. 5, Plate XXII., give the same for the last six months of 1865. Figs. 6 and 7 show the same for the twelve months of 1866.

The mean monthly integrals of chemical intensity for each month from April 1865 to April 1867, as obtained from these curves, are contained in the first column of the following Table. In the second column are given approximations to this integral obtained by taking the average of the daily means as given on Table II. (pp. 557 and 558). The third column contains the average amount of moisture for the month, in grains per cubic foot; the fourth the relative humidity for the month; the fifth the average amount of cloud at the times of observation; and the sixth the relation between the number of observations on which the sun was overcast (=1) and those made in sunshine.

TABLE IV.

Date.	Chemical Intensity.		Humidity.		Cloud.	
	I.	II.	III.	IV.	V.	VI.
1865.						overcast=1.
April	97·8	77·1	3·32	0·71	4·1	1·9
May	117·8	98·6	3·63	0·72	6·3	0·5
June	82·3	83·9	4·23	0·73	4·5	1·6
July	114·4	105·6	4·82	0·74	6·0	1·0
August	88·9	84·2	4·50	0·78	6·9	0·6
September	107·8	114·6	4·81	0·72	2·4	3·6
October	23·4	30·4	3·68	0·83	4·0	1·9
November	17·8	13·2	3·12	0·85	6·7	0·5
December	....	8·0	2·98	0·88	7·5	0·3
1866.						
January	15·0	15·9	2·82	0·85	6·0	0·5
February	24·3	24·2	2·63	0·81	6·4	0·5
March	34·5	30·6	2·49	0·81	5·6	0·4
April	52·4	49·9	3·02	0·80	6·3	0·7
May	78·9	70·0	2·83	0·67	5·0	0·8
June	92·3	86·1	4·52	0·76	6·6	1·0
July	106·9	111·9	4·33	0·73	6·0	0·9
August	94·5	95·2	4·29	0·74	7·2	0·5
September	70·1	100·3	4·13	0·83	6·4	0·7
October	29·5	40·2	3·82	0·88	6·3	0·7
November	15·6	17·7	2·96	0·83	5·3	0·9
December	....	14·0	3·09	0·88	6·9	0·4
1867.						
January	13·0	8·3	......	0·86	7·8	0·3
February	21·7	17·5	2·86	0·82	7·2	0·4
March	30·6	27·0	2·33	0·83	7·7	0·2

Although the curves of mean daily chemical intensity showing the variation from hour to hour are symmetrical, the chemical action for hours equidistant from noon being the same, this relation appears by no means to hold good for the curves of yearly chemical intensity. This is distinctly seen if we compare the monthly means for the two months about the vernal with the two about the autumnal equinox, for 1865, 1866, and 1867.

1865–67.	Mean Chem. Int.	1866.	Mean Chem. Int.
March 1867	30·5	March 1866	34·5
April 1865	97·8	April 1866	52·4
September 1865	107·8	September 1866	70·1
August 1865	88·9	August 1866	94·5

Or for 100 chemically active rays falling in the months of March and April 1865, 1866, and 1867 at Kew, there fell in the months of September and August 1865–66 167 rays, the sun's mean altitude being the same in both cases.

The curve, fig. 8, Plate XXII., exhibits the biennial variation of chemical intensity at Kew for the two years ending April 1, 1867. The yearly integral for the twelve months January–March 1867 and April–December 1865 is 55·7; whilst that for the twelve months of 1866 is 54·7.

The marked differences between the chemical intensities in spring and autumn must be caused by corresponding differences either in the amount of cloud or in the transparency of the atmosphere. From Table IV. (p. 561) it is seen that the mean amount of cloud in March 1867 and April 1865 is 5·9, and that in August and September 1865 =4·7; whilst the mean cloud for March and April 1866 is 5·9, and that for the corresponding autumn months=6·8. If the number of observations made when the sun is shining be compared with those made when the sun's surface is obscured by clouds, it is seen that of sixty-nine observations made in April 1865 the proportion between cloud and sunshine was as 1 to 1·9, whereas in the months of August and September, out of 130 observations the proportion between cloud and sunshine was 1 to 2·1. In 1866 out of 123 spring observations the relation is 1 cloud to 0·55 sunshine, and out of 122 autumn observations the relation was found to be 1 cloud to 0·60 sunshine. Hence it appears that the effect of varying amount of cloud has been eliminated by the number of the observations, and that the difference in chemical intensity cannot be ascribed to the presence of more cloud in the spring than in the autumn.

The only other possible explanation is to be sought in the difference in atmospheric transparency in spring and autumn, and the only indication which we at present possess of such variation in transparency is afforded by measurements of the hygrometric condition of the air, the increased transparency of moist air for the visible rays being well known. In March 1867 and April 1865 the mean amount of moisture was found to be 2·82 grains per cubic foot; in August and September 1865 it was 4·65 grains. In March and April 1866 the moisture was 2·8 grains, and in August and September 4·21 grains. This gives a relation of 1 to 1·65 for spring and autumn moisture 1865, and 1 to 1·50

for the same in 1866. Another important factor as influencing the transparency must not be overlooked, viz. the presence of finely divided solid particles which floating about produce the phenomenon of atmospheric opalescence. This, taken in connexion with the well known fact of the greater velocity of the winds in spring than in autumn, thus increasing the quantity of these floating particles in the spring, points to an explanation of the high autumnal and low vernal chemical intensity.

PART II.—THE PARÁ OBSERVATIONS.

Our knowledge concerning the distribution of the chemically active rays on the earth's surface is as yet very limited, and any conclusions with respect to the intensity of the chemical rays in the tropics have been, up to the present time, based upon the vague and unsatisfactory statements of photographers. According to photographic observations it would appear that in advancing from England towards the equator the difficulty of obtaining good pictures is increased, and more time is said to be required to produce the same effect upon a sensitive film under the full blaze of a tropical sun than in the gloomier atmosphere of London*. It is likewise stated† that in Mexico, where the light is very intense, from twenty minutes to half an hour was required to produce photographic effects which in England occupy but a minute; and it is said that travellers engaged in copying the antiquities of Yucatan have on several occasions abandoned the use of the photographic camera and taken to their sketch-books. Dr. DRAPER has also noticed certain differences of a similar kind between the light of New York and that of Virginia, and hence a supposition has been thrown out of the existence of a peculiar retarding action exerted by the luminous and the calorific rays upon the more refrangible and chemically active portion of the sunlight. In order to test the validity of these statements, it becomes a matter of great interest to determine directly the intensity of the chemically active rays in the tropics. Through the kindness of Messrs. ALFRED BOOTH and Co., of Liverpool, and thanks to the zeal and ability of my assistant, Mr. T. E. THORPE, I have been able to obtain such a set of measurements made at Pará, situated nearly under the equator in the northern province of the Brazils, and lying upon a branch of the Amazons, in longitude 48° 30′ West, and latitude 1° 28′ South.

The observations, the results of which are given below, were made at Pará by Mr. THORPE from the 4th to the 26th of April 1866, in a situation possessing a clear horizon. Owing to the rainy season having set in when the experiments were commenced, the changes in the chemical intensity as observed from hour to hour, and even from minute to minute, are very sudden and remarkable, and render a large number of daily observations necessary. These sudden changes are well represented in the curves, figs. 9, 10, 12, and 13, Plate XXI., showing the variation of chemical intensity at Pará during the

* GOLDING BIRD, 'Natural Philosophy,' p. 622, 5th Edit.

† ROBERT HUNT, 'Researches on Light,' p. 366.

days of April 18th, 23rd, 25th, and 26th. The curves for these days, compared with the dotted lines below, indicating the corresponding action at Kew, show the enormous variation in chemical intensity which occurs under a tropical sun in the rainy season. Regularly every afternoon, and sometimes at other hours of the day, enormous thunder-clouds obscure the sun, and discharging their contents in the form of deluging rain, reduce the chemical action nearly to zero. The storm quickly passes over and the chemical intensity rapidly rises to its normal value.

If we compare the daily mean intensities at Pará and Kew on the same days, we gain some idea of the true chemical action of the tropics, and it becomes at once evident that the alleged failure of photographers cannot, at any rate, be ascribed to a diminution in the sun's chemical intensity, but must rather be referred either to overexposure of the plate, or more probably to the difficulty of obtaining a distinct image owing to constant variation in the density of the layers of air intervening between the plate and the object. The curves, figs. 9 to 14, Plate XXI., exhibit graphically the relation of chemical intensity at Kew and Pará on the 18th, 23rd, 24th, 25th, and 26th of April 1866, these being chosen from the other sets of observations as being the most complete. The data for these five days' observations are found in the Tables at the end of this paper.

The following numbers give the Daily Mean Chemical Intensities at Kew and Pará for fifteen days in April 1866.

Date.	Daily mean Intensity.		Ratio.
	Kew.	Pará.	
1866.			
April 4 ...	......	269·4	
6 ...	28·6	242·0	8·46
7 ...	7·7	301·0	39·09
9 ...	5·9	326·4	55·25
11 ...	25·4	233·2	9·18
12 ...	55·8	203·1	3·66
13 ...	52·2	337·8	6·46
14 ...	38·5	265·5	6·89
18 ...	39·8	350·1	8·80
19 ...	75·2	352·3	4·68
20 ...	38·9	385·0	9·90
23 ...	80·4	350·1	4·35
24 ...	83·6	362·7	4·34
25 ...	73·7	307·8	4·17
26 ...	39·1	261·1	6·67
Mean intensity.	46·06	303·2	

Hence it appears that the chemical action of total daylight in the month of April 1866 was 6·58 times as great at Pará as at Kew.

In order to form an idea of the march of the daily chemical intensity under the equator in the sunshine, all the observations made when the sun's disk was unobscured by clouds have been collected, and a curve plotted out from the means thus obtained.

The following Table gives the results, and the curve, fig. 14, Plate XXI., exhibits the regular nature of the increase before and after noon. The curve is a symmetrical one, and exhibits a maximum at noon; the dotted curve is the curve of mean chemical intensity for April at Kew, and the relation between these two intensities is as 52·4 to 313·3, or a ratio of 1 to 5·98.

Mean time.	No. of observations.	Intensity.	Mean time.	No. of observations.	Intensity.
h m			h m		
7 3	11	0·196	12 54	13	0·981
7 54	11	0·389	2 5	17	0·820
9 24	8	0·789	2 54	14	0·664
10 1	19	0·871	3 57	7	0·406
11 5	27	0·983	4 49	4	0·223
12 1	21	1·028			

In a future communication I propose to discuss the relation between the chemical intensity of direct and diffuse sunlight at Kew, Pará, and Lisbon.

Chemical Intensity of Total Daylight at Pará, April 12th, 1866.

Solar time.	Chemical intensity.	Condition of solar disk.	Clouds.	Temperature ° C.		Barometer.
				Dry.	Wet.	
h m						millims.
9 30	0·348	Clouded; dull.	9–10	28·1	25·7	764·4
9 45	Rain.					
9 55	0·731	....	9–10	28·4	26·4	
10 0	Rain.					
10 25	0·947	Unclouded.	8	29·4	28·3	
10 35	Rain.					
10 55	Id.					
11 2	0·971	Unclouded.	7–8	29·4	27·3	
11 30	1·019		7	31·1	27·2	
11 55	1·019	Unclouded.	5	30·1	25·9	764·2
1 14	0·968	Id.	6	27·8	26·1	
2 20	......	Very heavy rain.	......	......	......	763·0
2 45	0·744		10	27·8	26·6	
3 0	0·190	Gloomy; thunder.	10	26·6	25·0	
3 13	Rain.					
4 30	......	Heavy rain.				

Chemical Intensity of Total Daylight at Pará, April 13th, 1866.

Solar time.	Chemical intensity.	Condition of solar disk.	Clouds.	Temperature ° C.		Barometer.
				Dry.	Wet.	
h m						millims.
7 13	0·336	Unclouded.	2	24·6	34·0	763·5
8 0	......	....	3	25·8	24·4	
9 30	0·851	....	3	29·1	25·9	
10 0						
10 20						
10 45	0·565	Clouded.	7–8	30·0	25·9	
11 10	0·570	....	......	30·0	26·1	765·0
11 20	......	Rain.	8	30·5	26·7	
11 35	1·079	Sunshine.	......	31·4	27·6	
11 50	0·980	....	7–8	31·7	27·2	
12 10	0·665	Clouded.	......	32·0	27·2	
12 37	0·474		......	30·9	27·2	
1 0	1·080	Sunshine.	7	30·4	26·9	
1 10	......	Rain.	8			
1 42	0·210	Clouded.	8–9	26·8	25·6	
1 45	......	Thunderstorm.				
2 23	0·425	Sunshine cloud.	8	26·9	25·1	762·0
2 43	0·743	Unclouded.	7–8	28·2	25·9	
3 2	0·420	Sunshine cloud.	......	28·3	25·6	
3 15	0·378	....	8	28·1	25·3	
3 37	0·248	Clouded.	8	27·9	25·3	
4 0	......	Heavy rain.				

Chemical Intensity of Total Daylight at Pará, April 19th, 1866.

Solar time.	Chemical intensity.	Condition of solar disk.	Clouds.	Temperature ° C.		Barometer.
				Dry.	Wet.	
h m						millims.
6 50	0·227	Clouded.	5	24·5	24·3	766·5
7 15	0·333	Id.	5	25·0	24·4	
7 40	0·360	Id.	5	25·6	25·0	
8 0	0·416	Id.	9–10	26·6	25·6	
9 25	0·850	Unclouded.	6–7	28·4	26·0	
9 49	0·839	Id.	6–7	30·6	27·4	
9 52	0·803	Id.	6–7	30·6	27·4	
10 30	0·791	....	6–7	30·9	27·3	
10 47	1·266	Unclouded.	4–5	31·8	27·6	765·0
10 49	1·115	Id.	4–5	31·8	27·6	
11 25	0·900	Id.	5	32·6	27·6	
11 27	1·050	Id.	5	32·6	27·6	
12 41	0·940	Id.	3–4	33·3	27·8	
1 50	0·564	Clouded.	6–7	29·1	26·3	
2 15	1·000	....	6–7	28·1	25·6	762·5
2 46	0·739	....	9	29·4	26·3	
3 10	......	Heavy rain.				
3 30	0·260	Clouded.	9–10	26·2	25·3	
3 50	......	Rain.				

Chemical Intensity of Total Daylight at Pará, April 20th, 1866.

Solar time.	Chemical intensity.	Condition of solar disk.	Clouds.	Temperature ° C. Dry.	Temperature ° C. Wet.	Barometer.
h m						millims.
7 40	0·456	Unclouded.	1	26·1	25·0	764·5
9 53	0·940	Id.	1	29·4	26·1	
10 21	1·000	Id.	3	30·8	27·1	
10 48	0·768	Id.	3–4	31·7	27·5	
11 31	0·893	Id.; hazy.	4–5	32·2	27·2	764·5
12 0	0·900	Id.; id.	4–5	34·1	28·1	
12 32	0·960	Id.	4–5	34·3	27·8	
1 2	0·908	Id.	......	33·7	28·2	
3 5	0·336	Clouded; gloomy.	8	31·9	27·2	
3 16	0·237	Id.; id.	8–9	31·3	27·5	
3 40	0·539	....	7–8	29·4	26·4	
4 0	0·452	Unclouded.	7–8	27·8	25·7	
4 20	0·333	Clouded.	7–8	28·4	26·1	

Chemical Intensity of Total Daylight at Pará, April 23rd, 1866.

Solar time.	Chemical intensity.	Condition of solar disk.	Clouds.	Temperature ° C. Dry.	Temperature ° C. Wet.	Barometer.
h m						millims.
9 5	0·761	....	7	28·1	25·9	766·5
9 15	0·532	Clouded.	8	28·1	25·8	
9 30	1·079	....	6	28·4	26·1	
9 45	0·725	Clouded.	5	29·4	26·5	
10 0	1·402	Unclouded.	4	29·6	26·5	
10 15	1·019	....	5	29·4	26·2	
10 30	1·105	Unclouded.	4	30·6	26·4	
10 45	1·114	Id.	4	29·6	27·0	
11 0	1·148	Id.	4	31·6	27·2	
11 17	1·318	Id.	4	32·9	27·4	
11 30	0·674	Clouded.	5	32·5	27·2	765·8
11 45	1·019	Unclouded.	3			
12 0	1·019	Id.	3	32·8	26·1	
12 15	1·054	Id.	3–4	32·2	25·7	
12 30	1·344	Id.	4	32·1	25·3	
12 45	0·689	Clouded.	8	31·7	25·4	
1 0	Rain.					
1 12	0·444	Clouded.	8	......	......	764·5
1 30	1·002	Unclouded.	4	29·0	26·1	
1 50	0·874	....	7	30·0	26·1	
2 5	0·925	....	7	30·0	26·1	
2 15	0·968	....	7–8	30·6	26·6	
2 30	0·925	....	7–8	30·9	26·6	
2 45	0·977	....	7–8	31·1	26·6	
3 0	0·856	Unclouded.	6	30·9	26·6	
3 15	0·280	Overcast; gloomy.	8–9	28·9	26·1	763·5
3 30	0·384	Id.; id.	9–10	27·8	25·7	
3 45	0·352	Overcast.	9–10	27·2	25·1	
4 0	Rain.					
5 0	0·233	Overcast.	8–9	25·7	24·8	
5 10	0·200	Id.	8	25·7	25·0	
5 20	Rain.	....	......	......	......	764·0

Chemical Intensity of Total Daylight at Pará, April 24th, 1866.

Solar time.	Chemical intensity.	Condition of solar disk.	Clouds.	Temperature ° C. Dry.	Temperature ° C. Wet.	Barometer.
h m						millims.
6 55	0·151	Sunshining through mist.	......	24·4	24·2	763·5
7 30	0·213	Clouded.	9–10	25·6	24·9	
8 0	0·359	Id.	8	26·6	25·6	
9 31	0·633	Thin haze.	2	29·4	26·4	
10 2	0·684	Unclouded.	2	30·0	26·4	767·0
10 30	0·719	Id.	2	30·6	26·1	
11 3	0·951	Id.	3	32·3	27·8	
12 0	1·019	Id.	4	31·7	25·9	
1 0	0·942	Id.	......	31·7	25·3	
2 0	0·754	Id.	4	32·2	26·1	764·5
3 0	0·492	Id.	2	32·2	25·1	
3 51	0·389	Id.	3	30·1	26·6	762·5
4 29	0·306	Id.	3–4	29·0	26·2	

Chemical Intensity of Total Daylight at Pará, April 25th, 1866.

Solar time.	Chemical intensity.	Condition of solar disk.	Clouds.	Temperature ° C. Dry.	Temperature ° C. Wet.	Barometer.
h m						millims.
6 48	0·116	Unclouded.	0·5	24·2	23·6	765·5
7 31	0·312	Id.	0·5	25·9	25·0	
9 41	0·490	Clouded over.	......	29·4	25·4	766·8
10 3	0·762	Unclouded.	3–4	31·3	27·0	
10 29	0·944	Id.	5	31·9	26·5	
10 53	0·529	Clouded over.	4–5	31·1	26·2	
10 55	0·959	Unclouded.	4–5	31·1	26·2	
11 29	0·475	Clouded over.	6–7	32·7	27·4	
11 30	0·976	Unclouded.	6–7	32·7	27·4	
11 45	0·479	Clouded over.	5	32·2	26·6	766·0
12 0	1·011	Unclouded.	5–6			
12 16	0·977	Id.	5	32·0	26·1	
12 47	0·882	....	......	31·3	26·9	
1 0	0·335	Overcast; gloomy.	......	29·7	26·6	
1 23	0·365	Id.; id.	......	29·7	26·7	
1 47	0·774	Unclouded.	5	30·8	27·5	
2 39	0·236	Clouded over.	8	28·3	26·1	
2 45	Rain.					
3 6	0·677	Unclouded.	7–8	29·7	27·2	763·0
3 45	Rain.					
3 49	0·210	Clouded.	9	28·3	26·1	
4 5	Rain.					

Chemical Intensity of Total Daylight at Pará, April 26th, 1866.

Solar time.	Chemical intensity.	Condition of solar disk.	Clouds.	Temperature ° C.		Barometer.
				Dry.	Wet.	
h m						millims.
7 43	0·360	Unclouded.	2	26·3	25·3	766·0
8 19	0·408	Clouded.	7–8	26·7	25·0	
10 0	0·958	....	7–8	30·8	26·6	767·0
10 15	0·354	Clouded; gloomy.	10	29·4	26·1	
10 30	0·608	Id.; id.	9	28·9	25·6	
10 45	0·650	Id.	9	30·0	26·0	
11 0	0·822	....	8–9	29·9	26·4	766·5
11 15	1·037	....	7–8	31·7	27·2	
11 30	1·088	Unclouded.	7	32·2	27·5	
11 45	1·011	Id.	5	31·1	25·6	
12 0	0·539	Clouded.	5–6	30·8	25·0	765·5
12 10	1·036	Unclouded.	3–4	31·0	25·5	
12 30	0·976	Id.	3	32·2	26·6	
1 20	0·831	Id.	5	32·3	25·8	
2 13	0·608	Id.	5	31·9	25·0	
2 33	0·540	Id.	6–7	29·7	26·4	763·8
2 53	0·336	Clouded.	8	27·4	24·7	
3 0	Rain.					
3 30	Rain.					
3 34	0·200	....	8–9	26·3	25·3	763·5
3 46	0·166	Clouded.	8–9	26·3	25·3	

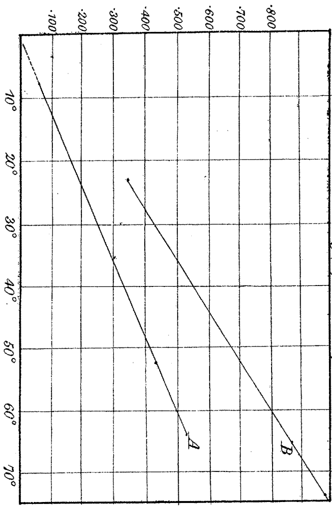


Fig. 1. Heidelberg (A). Para (B).

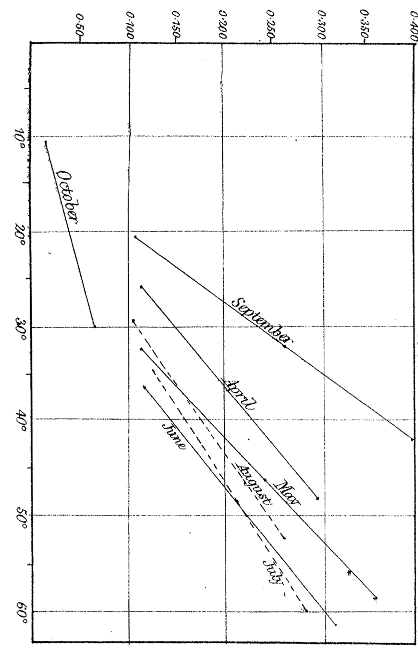


Fig. 2. 1865.

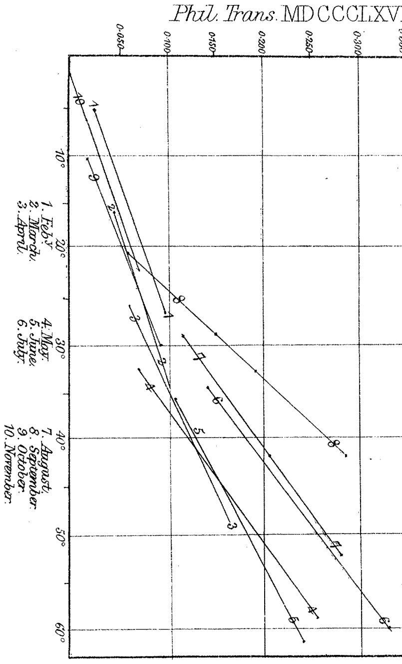


Fig. 3. 1866.

Fig. 9.
April 18th 1866.

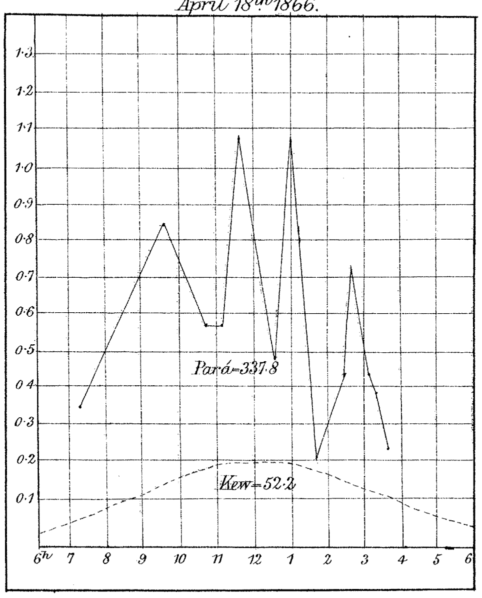


Fig. 10.
April 23rd 1866.

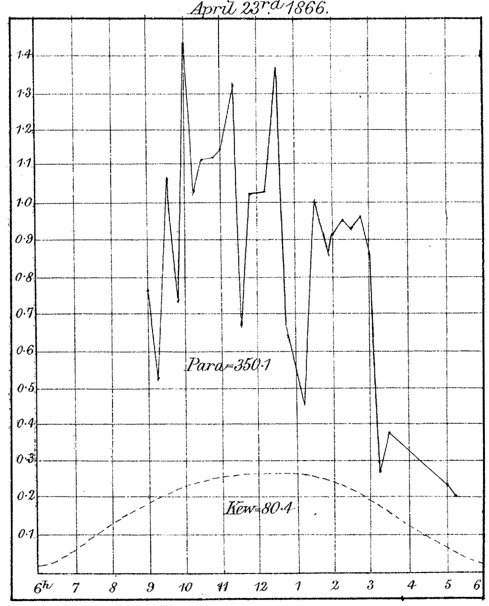


Fig. 11.
April 24th 1866.

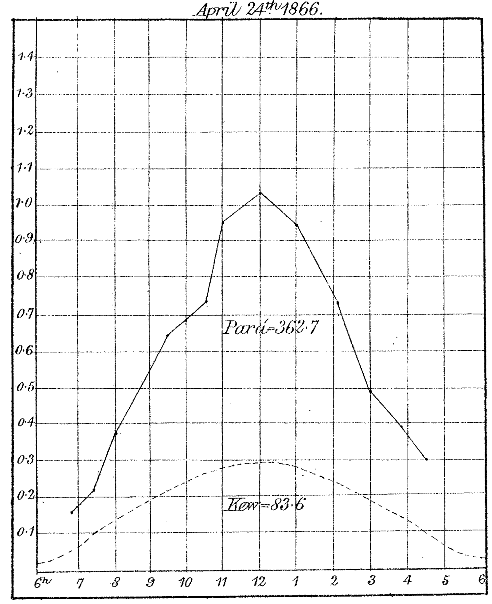


Fig. 12.
April 25th 1866.

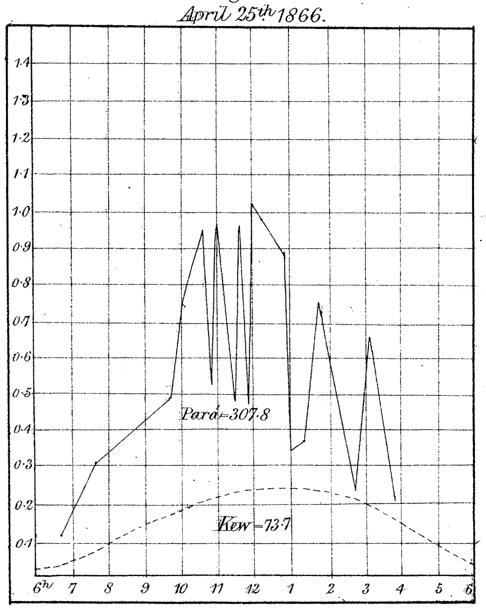


Fig. 13.
April 26th 1866.

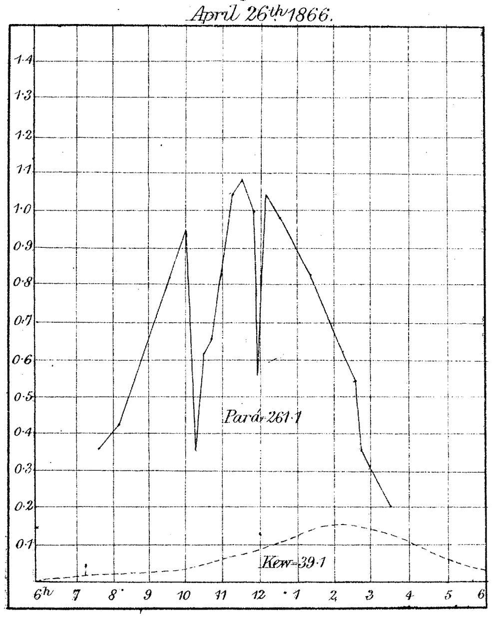
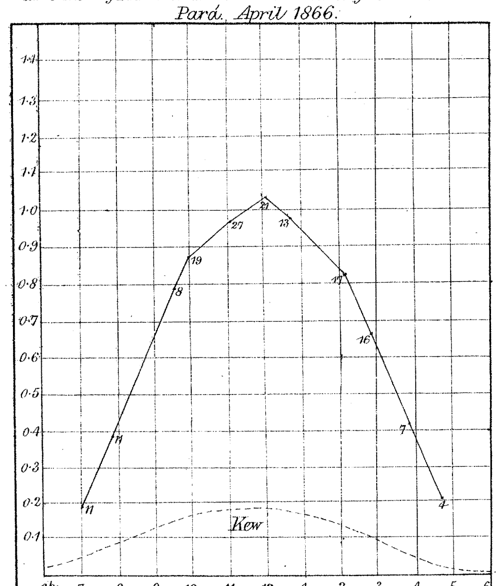


Fig. 14.
Curve showing March of Total Chemical Intensity for Sunshine.
Pará. April 1866.



J. Basire lith.

Fig. 4.

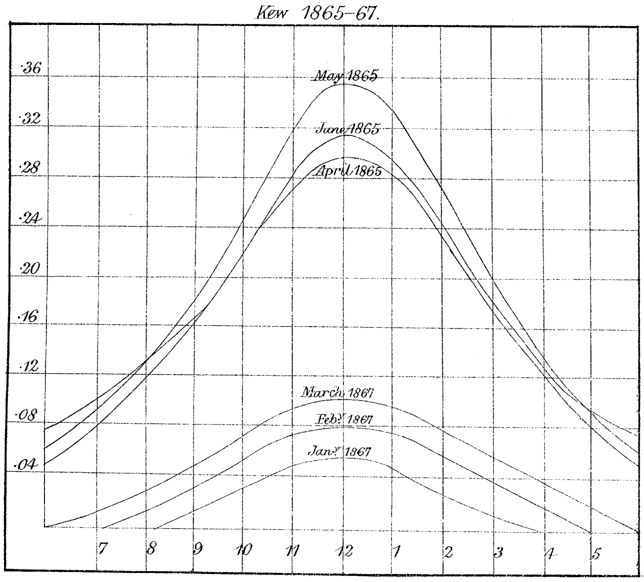


Fig. 5.

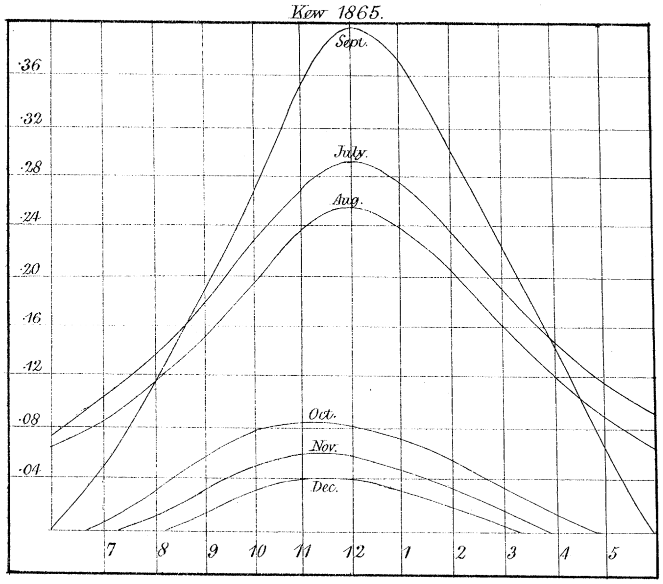


Fig. 6.

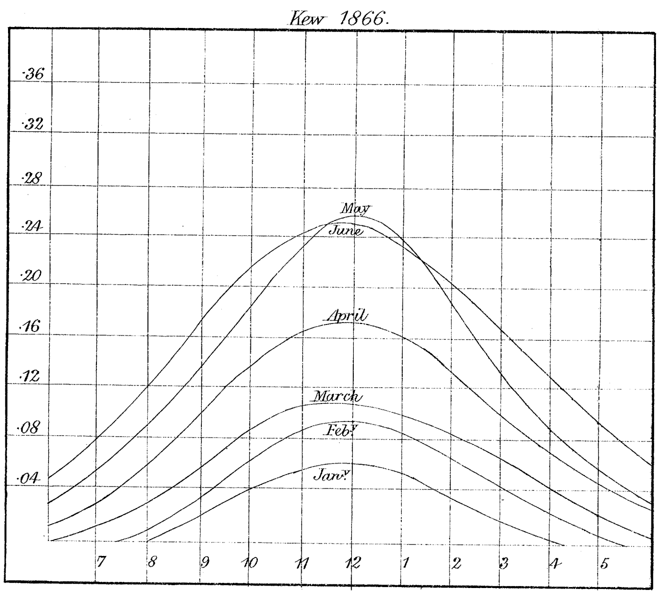


Fig. 7.

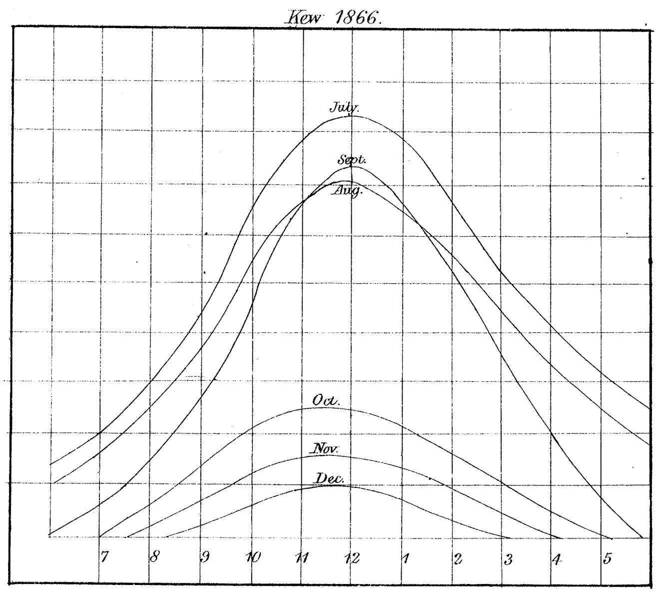
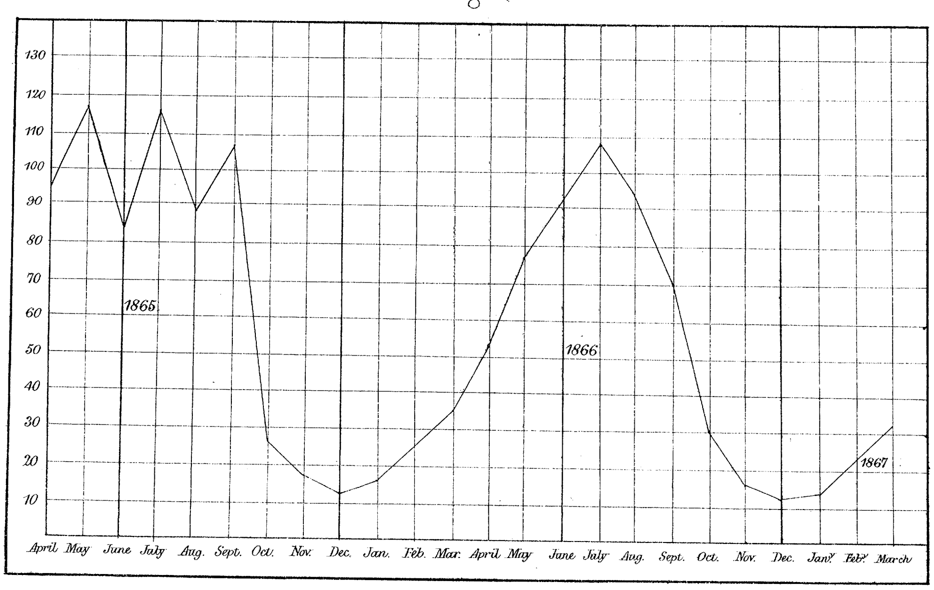


Fig. 8.



J. Basire litho.